Chilled Ceilings / Beams
Working Principles & Applications

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Chilled Ceilings / Beams
Working Principles & Application

Introduction

Operating principles

Key advantages and concerns

Application to buildings in Hong Kong – Trial calculations

Experience with pilot installations
New Trends: What Are They?

- Chilled beams (passive and active)
- Chilled (or heated) ceilings, floors, etc.
- Displacement air systems
- Low temperature air systems
- High induction diffusers

58% Overall Reduction in Energy Consumption

Chilled ceilings or chilled beams are widely used in buildings designed for an energy use level below those of conventional buildings by 50% or more.
• Chilled ceiling / beam originated and are widely used in Europe
• Chilled ceiling / beam are penetrating the US market
• Chilled ceiling / beam projects in Beijing
• Chilled ceiling / beam projects in Guangzhou
  • PEARL RIVER TOWER
    • 2.3 million sq ft
    • 71 storeys, 310m

Radiant cooling
- "chilled radiant" ceiling through perimeter chilled beams is used instead of normal ventilation and air conditioning.
- Cold water pumped (at approx 14.5deg C) through copper pipes in the slab which cool curved metal plates used for the ceiling system and metal fins for the perimeter, consequently cooling the surrounding air.
- chilled air cools the office space below and above.

Displacement ventilation
- provides only fresh air that is cooled by the chilled-water system and delivered via a raised access floor.

Metal ceiling system
### Chilled ceiling / beam projects in Hong Kong

<table>
<thead>
<tr>
<th>#</th>
<th>Project</th>
<th>Project Nature</th>
<th>System installed</th>
<th>Area (m²)</th>
<th>Year of Completion</th>
<th>Owner/ User</th>
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<tbody>
<tr>
<td>1</td>
<td>HAECO CLK Building - Office</td>
<td>Renovation</td>
<td>Chilled Ceiling</td>
<td>720</td>
<td>2011</td>
<td>HAECO</td>
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<td>2</td>
<td>Chinese University, meeting room</td>
<td>Renovation</td>
<td>Chilled Beam</td>
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<td>Chinese University</td>
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<td>3</td>
<td>Wong &amp; Ouyang BS Ltd. Office,</td>
<td>Renovation</td>
<td>Chilled Beam</td>
<td>250</td>
<td>2013</td>
<td>W&amp;O BS Ltd.</td>
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<td>4</td>
<td>Hang Seng Tower, 10 Floors</td>
<td>Renovation</td>
<td>Chilled Beam</td>
<td>10,000</td>
<td>2013</td>
<td>Hang Seng Bank</td>
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<tr>
<td>5</td>
<td>Hang Seng Management College, Block D, 3/F – 8/F (6 Floors)</td>
<td>New Construction</td>
<td>Chilled Ceiling</td>
<td>5,000</td>
<td>2013</td>
<td>Hang Seng Management College</td>
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<tr>
<td>6</td>
<td>HSBC Data Centre at STTL 433, Shek Mun, Shatin, 7/F – 10/F office</td>
<td>New Construction</td>
<td>Chilled Ceiling + Chilled Beam</td>
<td>9,000</td>
<td>2013</td>
<td>HSBC</td>
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<td>7</td>
<td>Hong Kong Science Park Phase 3, Conference Room</td>
<td>New Construction</td>
<td>Chilled Beam</td>
<td>80</td>
<td>in progress</td>
<td>HK Science Park</td>
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</tbody>
</table>
What are the key concerns that hinder wider adoption of chilled ceilings / beams in buildings in Hong Kong?

How can the perceived problems be resolved?
• Comfort air-conditioning

Heat exchange of human body with the environment

Heat transfer by convection, $C$

Heat transfer by radiation, $R$

Room climate:
- air temperature
- humidity

Distribution of daylight

Fresh air supply

Solar radiation (heat / light)

Air velocity
• Comfort air-conditioning

Heat exchange of human body with the environment

Heat transfer by convection, $C$

Heat transfer by radiation, $R$

Conventional AC system

AHU

Ch. W
S&R
• Comfort air-conditioning

Heat exchange of human body with the environment

Conventional AC system

- Actively controlling the indoor air temperature, $t_a$
- No active control over the temperatures of surfaces enclosing the space
• Comfort air-conditioning

Heat exchange of human body with the environment

Conventional AC system

- Actively controlling the indoor air temperature, $t_a$
- No active control over the temperatures of surfaces enclosing the space

$\overline{t}_r = \text{mean radiant temperature (a weighted mean value of temperatures of all surfaces to which the occupant is exposed)}$
Operating principles

• Comfort air-conditioning

Heat exchange of human body with the environment

Conventional AC system

• Actively controlling the indoor air temperature, $t_a$

• No active control over the temperatures of surfaces enclosing the space

• Operative temperature, $t_o$, represents the combined effect of $t_a$ and $t_r$

$$t_o = \frac{h_r t_r + h_c t_a}{h_r + h_c}$$

$t_r$ = mean radiant temperature (a weighted mean value of temperatures of all surfaces to which the occupant is exposed)
Operating principles

• Comfort air-conditioning

Heat exchange of human body with the environment

**Conventional AC system**

- Actively controlling the indoor air temperature, $t_a$
- No active control over the temperatures of surfaces enclosing the space
- Operative temperature, $t_o$, represents the combined effect of $t_a$ and $t_r$

$$t_o = \frac{h_r t_r + h_c t_a}{h_r + h_c}$$

$t_r = \text{mean radiant temperature (a weighted mean value of temperatures of all surfaces to which the occupant is exposed)}$
Operating principles

• Comfort air-conditioning

Heat exchange of human body with the environment

Lowering mean radiant temperature ($t_r$) allows indoor air temperature ($t_a$) to be raised without affecting operative temperature ($t_o$) and thus thermal comfort sensation of occupants.

Conventional AC system

• Actively controlling the indoor air temperature, $t_a$

• No active control over the temperatures of surfaces enclosing the space

• Operative temperature, $t_o$, represents the combined effect of $t_a$ and $t_r$

$$t_o = \frac{h_r t_r + h_c t_a}{h_r + h_c}$$

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Operating principles

- Comfort air-conditioning

Heat exchange of human body with the environment

- Heat transfer by convection, $C$
- Heat transfer by radiation, $R$

DOAS = Dedicated Outdoor Air System
PA = Primary Air
• Comfort air-conditioning

Heat exchange of human body with the environment

Chilled ceiling panels

Room climate:
- air temperature
- humidity

Heat transfer by convection, C

Heat transfer by radiation, R

Sensible heat only  Sensible heat only

Solar radiation (heat / light)

Air velocity

Sensible and latent heat

DOAS or PA system

PAU

DOAS = Dedicated Outdoor Air System
PA = Primary Air
• Chilled ceiling

Radiant chilled ceiling components

Type WK-D-UG

- Can fit in all ceiling tiles
- Assembly of ceiling tiles and chilled ceiling components at the factory
- Can be incorporated into a plaster ceiling
- Cooling capacity up to 80 W/m²

Type WK-D-UM

Type WK-D-UL

- Can fit in all commercial ceiling tiles
- Can be incorporated into a plaster ceiling
- Easy assembly
- Cooling capacity up to 80 W/m²
Operating principles

- Chilled ceiling

Where the cooling requirement exceeds the capacity limit of chilled ceiling panels (~80W/m²), chilled beams may be used instead.
Operating principles

• Chilled beam

Passive chilled beams
Type PKV

Multi-service chilled beams
Type PKV-B

- Design variants with perimeter border and perforated face plate
- Freely suspended or flush ceiling installation
- L: 900 – 3000 mm · W: 180 – 600 mm
  H: 110 – 300 mm
- Cooling capacity up to 1440 W

- Attractive design in a low height construction
- Also for heating operation
- Integration of linear light fittings and halogen spotlights
- Freely suspended installation
- Project bespoke multi-service integration
- L: 3200 mm · W: 525 mm · H: 70 mm
- Cooling capacity up to 255 W
- Heating capacity up to 530 W
Operating principles

- Chilled beam

The cooling capacity of passive chilled beams can be up to 350 - 475W/m² (Based on their exposed face area – clearance spaces needed between chilled beams)

Multi-service chilled beams

Type PKV-B

Attractive design in a low height construction
Also for heating operation
Integration of linear light fittings and halogen spotlights
Freely suspended installation
Project bespoke multi-service integration

L: 3200 mm · W: 525 mm · H: 70 mm
Cooling capacity up to 255 W
Heating capacity up to 530 W
• Chilled beam

Active chilled beam
Type DID312

- Four options of induced air grille design
- Heat exchanger vertically mounted with condensate drip tray for low chilled water temperatures
- Side entry spigot for fresh air
- Supply-extract-air combination available

- L: 900 – 3000 mm · H: 210 and 241 mm
- 5 – 70 l/s · 18 – 252 m³/h fresh air
- Cooling capacity up to 1800 W
- Heating capacity up to 1250 W

Type DID300B

- Side or top entry spigot for fresh air
- Supply-extract-air combination available

- L: 900 – 3000 mm · H: 210 mm
- 3 – 45 l/s · 10 – 160 m³/h fresh air
- Cooling capacity up to 1600 W
- Heating capacity up to 1250 W
Operating principles

- Chilled beam

**Active chilled beam**

**Type DID312**

- The cooling capacity of active chilled beams can be up to 700 - 1250W/m² (Based on their exposed face area – even greater clearance spaces needed between chilled beams)

**Type DID300B**

- Side or top entry spigot for fresh air
- Supply-extract-air combination available
- L: 900 – 3000 mm • H: 210 mm
- 3 – 45 l/s • 10 – 160 m³/h fresh air
- Cooling capacity up to 1600 W
- Heating capacity up to 1250 W
Operating principles

• Key characteristics of a chilled ceiling or chilled beam system:

There must be two systems operating in parallel:

• Chilled ceiling panels or chilled beams
  • Which extract (only) sensible heat from the spaces

• A primary air (PA) system or dedicated outdoor air system (DOAS)
  • Which supply ventilation air as well as remove ALL moisture gains (latent cooling loads) and a fraction of the sensible heat gains of the spaces
• Key advantages

  Radiant cooling by using chilled ceiling

  • Enhances thermal comfort and

  • Allows use of slightly higher indoor dry-bulb temperature set point


Principal advantages of panel systems are the following:

• Because not only indoor air temperature but also mean radiant temperature can be controlled, total human thermal comfort may be better satisfied.

• Comfort levels can be better than those of other space-conditioning systems because thermal loads are satisfied directly and air motion in the space corresponds to required ventilation only.
Key advantages and concerns

• Key advantages

- **Separation of dehumidification** (solely by PA system) from **sensible cooling** (by both PA system and chilled ceiling / beams) allows:
  - **Air flow rate** \( V_{PA} < V_{SA} \), and thus **fan power** and **noise**, to be **reduced** (although fan power saving **also achievable** in VAV systems)
  - **Use of higher temperature chilled water** for the chilled ceilings / beams, which helps save **chiller energy use** (low temp. Ch.W. still needed for PA system unless desiccant dehumidification is used)
Key advantages and concerns

- Key advantages
  - Reduced **ceiling space required** for installation
  - Reduced **maintenance cost**
    - When controlled properly, will not promote the formation of condensate which can lead to bacterial and mould growth
    - Do not require drain pans which require cleaning
    - Do not contain fans or filters to maintain and require only simple periodic service including vacuuming of the dry coil
Must ensure:

- The PA supply flow rate \( V_{PA} \) is sufficient, and the difference in moisture content between the indoor air and the PA supply \( (w_r - w_s) \) is large enough for the PA to offset the total moisture gain \( M_r \) of the room.

\[
M_r = \rho_a V_{PA} (w_r - w_s)
\]
Must ensure:

- The surface temperatures of the chilled ceilings / beams must be above the dew point temperature of the indoor air ($t_{dpr}$)
Must ensure:

- The **total sensible cooling capacity** of the chilled ceilings / beams ($Q_{SCC/B}$) is sufficient to offset the remainder of the room sensible load (with the sensible cooling effect of the PA discounted)

$$Q_{SR} = \text{Design room sensible cooling load}$$

$$Q_{SPA} = \text{Sensible cooling capacity of PA}$$

Where

$$Q_{SPA} = \rho_a V_{PA} C_P (t_r - t_s)$$

Required sensible cooling capacity of chilled ceilings / beams

$$Q_{SCC/B} >= Q_{SR} - Q_{SPA}$$
Key advantages and concerns

• Key concerns

  • Stagnant air flow and cold air dumping onto occupants

  • Condensation risk

  • Limited cooling capacity of chilled ceiling / beam modules

Impact on whether CC/B can be used
Key advantages and concerns

• Key concerns

  • **Stagnant air flow and cold air dumping** onto occupants
  
  • Condensation risk
  
  • Limited cooling capacity of chilled ceiling / beam modules

• Can be overcome by careful building and system design and operation

  • Maintain at least **1m clear headroom** between passive chilled beam and occupied zone (1.7m from finished floor level)
  
  • Use **active chilled beam**
  
  • Adequate **selection and layout** of chilled beams and/or diffusers for PA
  
  • Raise PA supply flow rate if absolutely needed
Key advantages and concerns

- **Key concerns**
  - Stagnant air flow and cold air dumping onto occupants
  - Condensation risk
  - Limited cooling capacity of chilled ceiling / beam modules

- **Can be overcome** by careful building and system design and operation
  - Minimize moisture gains of spaces
  - Ensure PA system has sufficient dehumidification capacity; if needed, use heat pipes or desiccant dehumidification
  - Use an appropriate Ch.W supply temperature setting
  - Monitor and control ceiling / beam surface temperature
Key advantages and concerns

- **Key concerns**
  - Stagnant air flow and cold air dumping onto occupants
  - Condensation risk
  - Limited cooling capacity of chilled ceiling / beam modules

- **Can be overcome** by careful building and system design and operation
  - Minimize envelope heat gains
  - Use energy efficient lighting
  - Use energy efficient appliances
  - Use active chilled beams
Application to buildings in Hong Kong

- **Trial calculations – reference conditions (office building in HK)**

<table>
<thead>
<tr>
<th>Design conditions</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design OA temperature, $T_o$</td>
<td>°C</td>
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</tr>
<tr>
<td>Design OA RH, $R_{Ho}$</td>
<td>%</td>
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<tr>
<td>Design OA moisture content, $w_o$</td>
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<tr>
<td>Design OA enthalpy, $h_o$</td>
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<td>Design RA RH, $R_{Hr}$</td>
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<tr>
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<tr>
<td>Design RA enthalpy, $h_r$</td>
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<td>Room floor area (Interior Zone)</td>
<td>m²</td>
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<tr>
<td>Room height</td>
<td>m</td>
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<tr>
<td>Room volume</td>
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<td>Lighting and app. power density</td>
<td>W/m²</td>
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<td>Lighting and appliances heat gain, $Q_{si}$</td>
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</table>

<table>
<thead>
<tr>
<th>Design conditions</th>
<th>Unit</th>
<th>Value</th>
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<tr>
<td>Occupancy rate</td>
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<tr>
<td>No. of Occupants</td>
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<td>Sensible heat gain per person</td>
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<td>Rad. Sen. heat gain from occupant</td>
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<tr>
<td>Latent heat gain per person</td>
<td>W/p</td>
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<td>Moisture gain per person</td>
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<td>Sensible load from occupants, $Q_{sp}$</td>
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<td>Latent heat gain from occupants, $Q_{lp}$</td>
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**Trial calculations – cooling load intensity**

Design cooling load predictions for Model **Office** Building by BEEP

<table>
<thead>
<tr>
<th>Floor</th>
<th>Space</th>
<th>DSL kW</th>
<th>DLL kW</th>
<th>DTL kW</th>
<th>Area m²</th>
<th>DSL W/m²</th>
<th>DLL W/m²</th>
<th>DTL W/m²</th>
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<tbody>
<tr>
<td>Typical</td>
<td>North</td>
<td>11.33</td>
<td>1.46</td>
<td>12.79</td>
<td>144.44</td>
<td>78.42</td>
<td>10.13</td>
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<tr>
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<td>14.39</td>
<td>1.20</td>
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### Trial calculations – **cooling load intensity**

**Design cooling load** predictions for Model **Office** Building by BEEP

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- **Shared between chilled ceilings / beams and PA system**
- **By PA system**
• Trial calculations – **PA flow rate**

![Graph showing PA flow rate vs. PA supply dew point temperature.](image-url)

**Indoor design temperature, relative humidity and dew point temperature**
Application to buildings in Hong Kong

- Trial calculations – **PA flow rate**

The higher the $t_{dpr}$, the smaller the $V_{pa}$

The lower the $t_{dps}$, the smaller the $V_{pa}$

The required **PA supply flow rate** $(V_{pa})$ is highly sensitive to the choices of the **indoor air state** $(t_{dpr})$ and the **PA supply air state** $(t_{dps})$.

Indoor design temperature, relative humidity and dew point temperature.
• Trial calculations – **PA flow rate**

Selected condition: Sensible cooling provided by PA = 18.13W/m²
Application to buildings in Hong Kong

- Trial calculations – Required chilled ceiling / beam cap.

<table>
<thead>
<tr>
<th>Floor</th>
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<th>DSL</th>
<th>PA S Cap</th>
<th>CC/B Cap</th>
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<td>18.13</td>
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- Chilled beams need to be used for the perimeter zones but chilled ceilings may be used for the interior zone.
Key design considerations

- Minimize sensible cooling load through
  - Reducing external heat gains by improving thermal performance of building envelope
  - Reducing internal heat gains by using energy efficient lighting and appliances

- Minimize latent cooling load through reducing ingress of humid air into air-conditioned space by
  - Improving air-tightness of building envelope
  - Positive pressurization of air-conditioned space
  - Use of anteroom (lobby with double-door) if needed
• Key design considerations

• Adequate selection of design indoor air state (an increase in RH by 5% can make a big difference)

• Adequate selection of design PA supply air state (the lower the moisture content in it the smaller the required PA supply flow rate), subject to the constraints of
  • Temperature of chilled water supply to PAU (may use desiccant dehumidification)
  • Minimum FA supply flow rate for air-conditioned spaces

• Adequate selection of temperature of chilled water supply to chilled ceilings / beams (at or slightly above dew point temperature of indoor air)
Experience with pilot installations

• Hui & Leung (2012)

  • Study on chilled ceiling application in Hong Kong
  
  • Simulation results: ~20% energy saving achievable

  • Field study – offices of an aircraft engineering company:
    
    • Chilled ceiling in use since mid-2011
    
    • 84% of the occupants satisfied with thermal sensation, though 40% felt temperature sometimes too hot
    
    • 51% felt air movement too low
    
    • Findings similar for another field study (construction site office)
Experience with pilot installations
Experience with pilot installations
Experience with pilot installations
Experience with pilot installations
End of Presentation

Thank you